

# **AN ASSESSMENT OF RIVER RESOURCES FOR LOUISIANA COASTAL LAND PRESERVATION**

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1. REPORT DATE <b>MAY 2008</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2008 to 00-00-2008</b>	
4. TITLE AND SUBTITLE <b>An Assessment of River Resources for Louisiana Coastal Land Preservation</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Biedenharn Group, LLC,Vicksburg,MS</b>				8. PERFORMING ORGANIZATION REPORT NUMBER <b>; -</b>	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) <b>-</b>	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>49</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

# **AN ASSESSMENT OF RIVER RESOURCES FOR LOUISIANA COASTAL LAND PRESERVATION**

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## LIST OF SYMBOLS, UNITS, AND ABBREVIATIONS

### Symbols

$\%TNP$	percent of nitrogen and phosphorus in plant biomass
$B$	average water width (ft)
$H$	average water depth (ft)
$P_r$	plant productivity rate
$TNP$	total nitrogen and phosphorus
$TNP_{background}$	background concentration of nitrogen and phosphorus (mg/L)
$TNP_{source}$	source concentration of nitrogen and phosphorus (mg/L)
$U_{tide,max}$	maximum tidal velocity (ft/s)
$z_o$	roughness height (m, ft)
$\rho_i$	upper-horizon (top 50 cm) bulk densities

### Units

%	percent
acres/yr, acre/yr <sup>-1</sup>	acres per year
cfs	cubic feet per second
cm	centimeter(s)
cm/yr	centimeter(s) per year
cu yds	cubic yards
cu yds/acre	cubic yards per acre
ft	feet
ft/s	feet per second
ft/yr	feet per year
g/cm <sup>3</sup> , g cm <sup>-3</sup>	gram(s) per cubic centimeter
g/cm <sup>3</sup> /m	gram(s) per cubic centimeter per meter
g/m <sup>2</sup> /yr	gram(s) per square meter per year
ha	hectare(s)
km	kilometer(s)
km <sup>2</sup>	square kilometer(s)
km <sup>2</sup> /yr, km <sup>2</sup> /yr <sup>-1</sup>	square kilometer(s) per year

m	meter(s)
m <sup>3</sup>	cubic meter(s)
m <sup>3</sup> /s, m <sup>3</sup> s <sup>-1</sup>	cubic meter(s) per second
mg/L, mg/L <sup>-1</sup>	milligram(s) per liter
mi	mile(s)
mm	millimeter(s)
mm/yr	millimeter(s) per year
mo	month
ppt	parts per thousand
RM	river mile
sq mi	square mile(s)
sq mi/yr, sq mi/yr <sup>-1</sup>	square mile(s) per year
T/km <sup>2</sup>	ton(s) per square kilometer
tons/mo	ton(s) per month
yds/acre	yard(s) per acre
yrs	years

## Abbreviations

CWPPRA	Coastal Wetlands Planning, Protection and Restoration Act
FWOP	future without project
GIWW	Gulf Intracoastal Waterway
IPCC	Intergovernmental Panel on Climate Change
LaCPR	Louisiana Coastal Protection and Restoration
LCA	Louisiana Coastal Area
LDNR	Louisiana Department of Natural Resources
Max	maximum
Min	minimum
MRGO	Mississippi River Gulf Outlet
NAVD	North American Vertical Datum
RSLR	relative sea-level rise
SRED	Sediment Enhancement Device

Std Dev	Standard Deviation
TSS	suspended sediment
USACE	U.S. Army Corps of Engineers

# **CHAPTER 1**

## **INTRODUCTION**

This report is a portion of a larger investigation addressing current and historical sediment loads in the Mississippi River. In this report, we address four primary tasks: 1) quantify sediment discharges from the Mississippi River at existing diversions; 2) assemble estimates of sediment quantiles and sediment sizes available for diversions planned to promote coastal marsh restoration; 3) develop estimates of sediment loads required for restorations and estimates of uncertainty; and 4) identify seasonal timing for diverting sediment from the river for marsh and wetland restoration.

## **CHAPTER 2**

### **BACKGROUND**

The quantity of technical literature pertaining to the problem of coastal Louisiana land loss is voluminous, and encompasses a wide variety of topics. A few of these topics will be covered to promote understanding of the complexity of the problem of the loss of Louisiana coastal lands.

Like most things in Louisiana, the coast was formed on give-and-take of natural processes: sediment from the various courses of the Mississippi being deposited to build the marshes and natural subsidence allowing the new land to sink below global sea-level rise. When the building of land was balanced by the subsidence and sea-level rise, the net land area was reasonably constant. However, in the last 200 to 300 years, human intervention has altered the long-term trend of the natural process, which has caused widespread land loss along the Louisiana coastline (National Academy of Science (NAS) 2006).

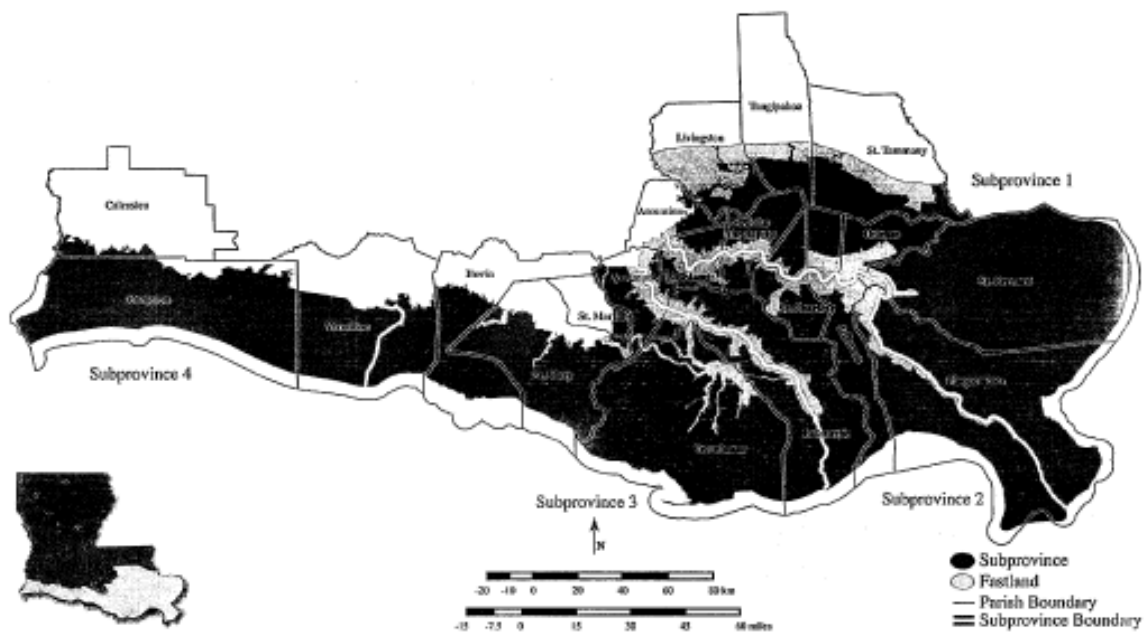
Numerous factors have contributed to the accelerated loss of coastal land. The following causes are frequently associated with the land-loss problem:

- Mining of natural resources has resulted in canals that have disrupted natural flow patterns in the marsh, altering the natural distribution of fresh and saline water.
- Flood control levees have restricted the movement of the Mississippi River that, over time, had formed a series of alternating lobes to feed water and sediment to the marsh; and, in protecting citizens and infrastructure, have confined the river flow to deliver the sediment to the Gulf of Mexico and not directly to the marsh.
- The relative sea-level rise (RSLR), subsidence, plus global rise, appear to be accelerating as a result of climate change.

In addition to these causes, the first portion of this report is directed to another potential cause: erosion control projects throughout the Mississippi River Basin have reduced the available sediment supply.

## 2.1 Land Loss

An important component in developing an estimate of sediment loads required for restoration of coastal Louisiana land is to establish the present and future rates of loss. Barras (2006) provides a recent study of land-area change in coastal Louisiana. His investigation focused on the effects of Hurricanes Katrina and Rita that occurred in 2005, and that study provides quantification of transitory land loss; however, estimation of permanent losses require several more years of data. The study (Barras 2006) also provided a map of the land loss for the 48-year period of 1956 to 2004, which included the effects of several hurricanes that are not specifically identified. The total land loss for the period was 1,149 sq mi [2,975 km<sup>2</sup>], averaging 23.9 sq mi/yr [61.9 km<sup>2</sup>/yr]. Barras *et al.* (2004) provide a thorough review of historical rates (1978 to present) and provide a projected rate of loss for the period to 2050. Figure 2.1 is a map of the Louisiana Coastal Area (LCA) boundaries that were used by Barras *et al.* (2004) to subdivide the study area. Table 2.1 provides a summary table of land-loss rates by subprovince for the period 1978 to 2000.



**Figure 2.1:** LCA subprovince boundaries are shown (after Barras *et al.* (2004)).

**Table 2.1: The data for net land-loss trends by subprovince for the period 1978 to 2000 are shown (after Barras *et al.* (2004)).**

	1978 - 1990	1990 - 2000	1978 - 2000		
	Net Loss	Net Loss	Cumulative	Annual	% Total Loss
	(sq mi)*	(sq mi)	Loss	Loss	by Area
	(sq mi)	(sq mi)	(sq mi)	(sq mi/yr)	
Subprovince 1	52	48	100	4.5	15.2%
Subprovince 2	148	65	213	9.7	32.4%
Subprovince 3	134	72	206	9.4	31.3%
Subprovince 4	85	54	139	6.3	21.1%
Total sq mi	419	239	658	29.9	100%
[km <sup>2</sup> ]	[1,085]	[619]	[1,704]	[77.4]	

\*1978 to 1990 net loss figures were based on Barras *et al.* (1994). The 1978 to 1990 basin level and coast-wide trends used in this study were aggregated to reflect LCA subprovinces for comparison with the 1990 to 2000 data. The basin boundaries used in Barras *et al.* (1994) were based on older CWPPRA planning boundaries and are not directly comparable to the LCA boundary used to summarize the 1990 to 2000 trend data. The 1990 to 2000 net loss figures include actively managed lands for comparison purposes with the 1978 to 1990 data.

In Table 2.2, Barras *et al.* (2004) explain that the projected change from 2000 to 2050 is a result of an estimated 674 sq mi of land loss and a gain of 161 sq mi [417 km<sup>2</sup>] related to existing restoring projects (Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) projects, Caernarvon, David Pond, and delta building at the mouth of the Mississippi and Atchafalaya Rivers). For the purposes of estimating the annual sediment required to stop coastal land loss, the total land loss of 674 sq mi [1,746 km<sup>2</sup>] is appropriate. This represents an annual loss rate of 13.5 sq mi/yr [35 km<sup>2</sup>/yr]. Barras *et al.* (2004) estimate the trend error range at  $\pm 25\%$ .

**Table 2.2: The projected net land-loss trends by subprovince are shown for the period 2000 to 2050 (after Barras *et al.* (2004)).**

	Land in	Land in	Net	% Land		% Total
	2000	2050	Land Loss	Loss	Land Loss	Loss by
	(sq mi)	(sq mi)	(sq mi)	between	(sq mi/yr)	Area
	(sq mi)	(sq mi)	(sq mi)	2050 and		
	(sq mi)	(sq mi)	(sq mi)	2000		
Subprovince 1	1,331	1,270	61	4.61%	1.23	12%
Subprovince 2	1,114	928	186	16.68%	3.71	36%
Subprovince 3	1,975	1,746	229	11.59%	4.58	45%
Subprovince 4	1,431	1,394	37	2.59%	0.74	7%
Total sq mi	5,851	5,338	513	8.77%	10.26	100%
[km <sup>2</sup> ]	[15,154]	[13,825]	[1,329]		[26.57]	

Note that total percentage of land loss is the percentage of total net land loss (513 sq mi) in 2050 to the existing land (5,851 sq mi) in 2000.

The method used by Barras *et al.* (2004), as they point out, can only be used for projection of future trends based on events that have occurred in the past. For example, factors such as past sea-level rise are assumed to continue at the same rate in the future; however, Barras *et al.* (2004) point out that over the last two decades, Louisiana marshes have adjusted to high rates of RSLR by as much as 1 cm/yr, which may be a sufficient rate to include in the projection given the challenge of estimating the future rate.

In addition to the uncertainty of sea-level rise, other factors introduce uncertainty. For example, much of the sediment that is supplied by the Atchafalaya River is from either the Mississippi River through the Old River control structure or from the Red River. Operation of the Old River control structure is now mandated to distribute 70% of the flow to the lower Mississippi River and 30% to the Atchafalaya River. This distribution could be changed. The Red River Waterway was authorized in 1968 and following completion of the five major navigation locks, the sediment delivery from the upper Red River basin to the Atchafalaya River dramatically changed. Since that time, the amount of erosion downstream of L.C. Boggs Lock & Dam 1 has increased and this erosion is supplying sediment to the Atchafalaya River. The effect of a decision to change the distribution of flow at Old River control or a decision to reduce the erosion on the Red River could affect sediment supplied by the Atchafalaya.

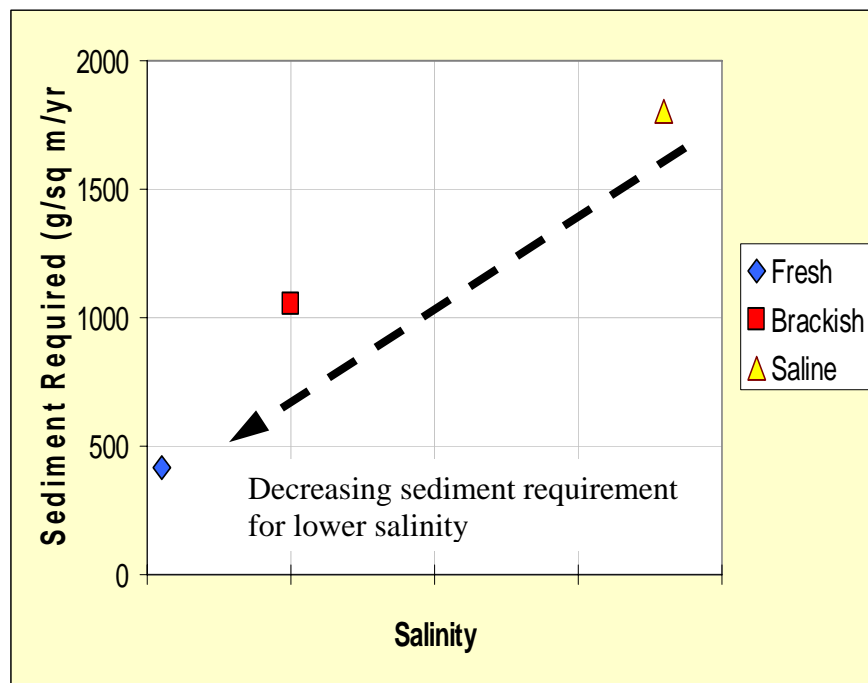
On a broad watershed scale, the effect of climate change on sediment delivery is challenging. Less river discharge may reduce sediment delivery, but a change to high-intensity rainfall and more flash flooding in the basin could make more sediment available for transport.

## **2.2 New Coastal Land**

DeLaune *et al.* (2003) report that Louisiana coastal marshes represent a thin veneer of primary organic soil material, which supports vegetative growth, and is overlying a mineral sediment layer deposited earlier by the present Mississippi River and previous distributaries. For locations in coastal Louisiana at which the vertical rate of accretion is less than the rate of RSLR, marsh deterioration can occur due to salt-water intrusion and other factors. Penland and Ramsey (1990) document submergence rates in the Mississippi River deltaic plain in excess of 1.0 cm/yr.

In many cases in Louisiana coastal marshes, organic-matter accumulation defines vertical accretion rather than mineral-matter accumulation (Hatton *et al.* 1983; Nyman *et al.* 1990). DeLaune *et al.* (2003) explain that even though marsh soil accretion is primarily through organic

accumulation, small quantities of organic matter are required for plant growth, to provide nutrients, and to supply iron that neutralizes sulfides that can be toxic to marsh vegetation. Nyman *et al.* (1990) reported that salt marsh requires a greater quantity of sediment in the soil profile to support plant growth than in freshwater marsh. Figure 2.2, developed using data estimated by Nyman *et al.* (1990) and proposed by DeLaune *et al.* (2003) illustrates that decreasing salinity, for example by freshwater diversion, reduces the quantity of sediment required for successful coastal marsh rehabilitation.



**Figure 2.2:** The amount of sediment required to meet marsh restoration goals is a moving target, and by reducing salinity (more freshwater) the amount of sediment required is decreased (after DeLaune *et al.* (2003)). Data estimated by Nyman *et al.* (1990).

Quoting DeLaune *et al.* (2003): *To maximize marsh creation at Mississippi River freshwater diversions sites, the critical nutrient, salinity and mineral sediment required for acceleration of plant biomass production (the source of peat or organic soil formation) should be provided. If the specific nutrient, salinity level and mineral sediment requirements for marsh*

*maintenance are known for a certain marsh area in the region, diverted water could be more effectively directed or distributed, maximizing marsh creation over a larger area.*

McKay *et al.* (2008) emphasize that the character of the discharge body may influence the relative importance of organic or inorganic inputs (Boustany 2007). They suggest that if a region is initially unvegetated, sediment inputs will be necessary to establish a soil platform for dense vegetative growth. With the establishment of dense vegetative growth, organic inputs may dominate, and the dense vegetation will encourage retention of a high percentage of suspended sediment. This positive feedback system necessitates inclusion of both sediment and vegetative inputs in planning the required vertical accretion for long-term stability.

## 2.3 Diversions

The New Orleans District furnished a listing of fifteen Mississippi River diversions recognized in their HEC-6T model. This list is presented as Table 2.3. Several existing diversions were investigated to provide information for the primary tasks, including the controlled diversions at Old River, Caernarvon, and Davis Pond; the uncontrolled diversion at West Bay; and several direct dredge-disposal sites. These sites include a broad range of discharge capacity, complexity, and detail of available data.

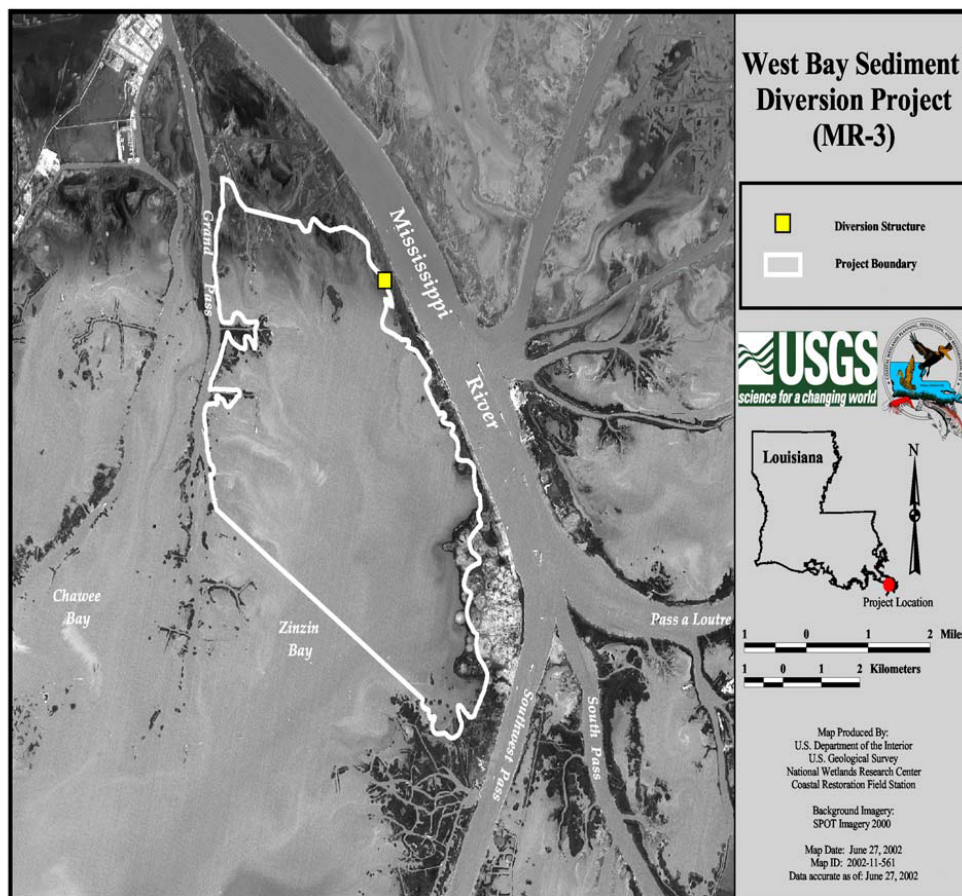
**Table 2.3: Mississippi HEC-6T diversions.**

<b>Diversion</b>	<b>Mile</b>
Burrwood Bayou	-14.4
Outlets 11.8W W-1 W-2	-10.7
Joseph Bayou and Overbank Flows	-4.5
Southwest Pass @ Mile 3.0 West	-3.05
South Pass and Pass-a-Loutre	0
Cubits Gap and Overbank Flows	3.15
West Bay Diversion Canal	3.83
The Jump	10.5
Baptiste Collette	11.5
Bohemia Spillway	45
Caernarvon	81
Davis Pond	108.1
Bonnet Carre Spillway	125
Bonnet Carre Diversion Structure	128
Old River Outflow Channel	310.6

Three existing projects were chosen for further discussion based on available data and are representative of three types of diversion: 1) West Bay Sediment Diversion, 2) Caernarvon Freshwater Diversion, and 3) Bayou LaBranche Wetland Creation. Each project utilizes different techniques to create wetlands, and each of these three projects has rigorous documentation of project aspects.

### 2.3.1 West Bay Sediment Diversion

The West Bay Sediment Diversion project, located at River Mile (RM) 4.7 above Head of Passes on the right descending bank, is an example of an artificial crevasse. The project area, shown in Figure 2.3, is composed of 12% freshwater marsh and tidal flats and 88% open water, for a total of 12,294 acres (4,975 ha) (Carter 2003).



**Figure 2.3:** Vicinity map of the West Bay Sediment Diversion project is shown.

Processes that form land in the lower Mississippi River Delta are important to recognize and to gain some understanding of the spatial and temporal scales of the formation of sub-deltas and crevasse splays. The following explanation is taken from LDNR (Carter 2003) and Andrus (2007). Sub-deltas are smaller versions of the deltaic cycle, reduced both in size and time of formation. Coleman and Gagliano (1964) document that sub-deltas consist of relatively large receiving bays (300 to 400 km<sup>2</sup>) with depths of 10 to 15 m. Boyer (1996) suggests that crevasse splays are approximately 0.6 km<sup>2</sup> in extent. In nature, crevasse splays are developed as the natural levee of a major channel is eroded and deliver sediment-rich river flow to adjacent bays. Changing energy to deliver available sediments tend to distribute materials by size; with clays and organic material along the forward periphery of active deposition, followed by silts and colloidal clays that may be colonized by marsh vegetation, and finally by sands that are deposited closest to the crevasse origination (Coleman and Gagliano 1964, Andrus 2007). As flow from the crevasse diminishes, the sub-delta ceases to grow and begins to subside. The life cycle of a sub-delta may be tens of years to hundreds of years, depending on the size of the depositional extent. The spatial and temporal scales that are manifest with artificial sub-delta and crevasse-splay development require consideration of time periods beyond accepted engineering perspectives.

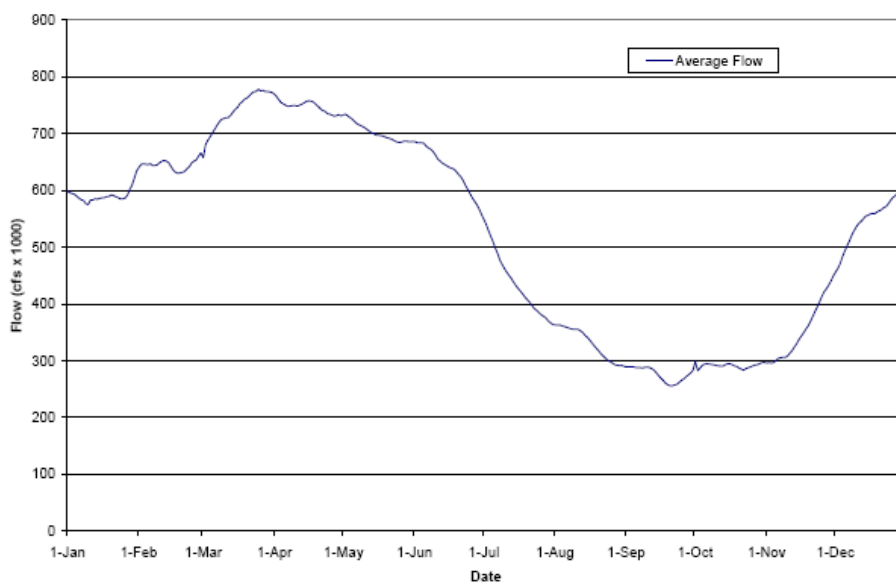
Creating artificial crevasses has been documented (LDNR; Carter 2003) to be successful in creating new wetlands: three crevasses in 1986 (Pass-a-Loutre, South Pass, and Loomis Pass) produced over 266 ha of emergent marsh in six years; and four crevasses in 1990 (South Pass and Pass-a-Loutre) produced 162 ha of emergent marsh in three years (LDNR; Carter 2003, Trepagnier 1994). Kelly (1996) also documented that the LDNR Small Sediment Diversions project cumulatively produced 127 ha of emergent marsh during the 1986 to 1993 period.

The purpose of the West Bay Sediment Diversion project is to promote the formation of emergent marsh by construction of an artificial crevasse (Carter 2003). To achieve the initial design discharge, a cut through the levee was dredged that was approximately 25-ft deep and a level section 95-ft wide. Andrus (2007) states that a Sediment Enhancement Device (SRED), a low weir to enhance deposition, was not constructed and could be added later as the 20,000 cubic feet per second (cfs) discharge of Phase 1 was increased to 50,000 cfs in a later phase. He also alludes to studies by Roberts (1997) concerning wind-driven wave currents that detrimentally affect the deposition efficiency. On the Wax Lake outlet, wind driven re-suspension of sediment

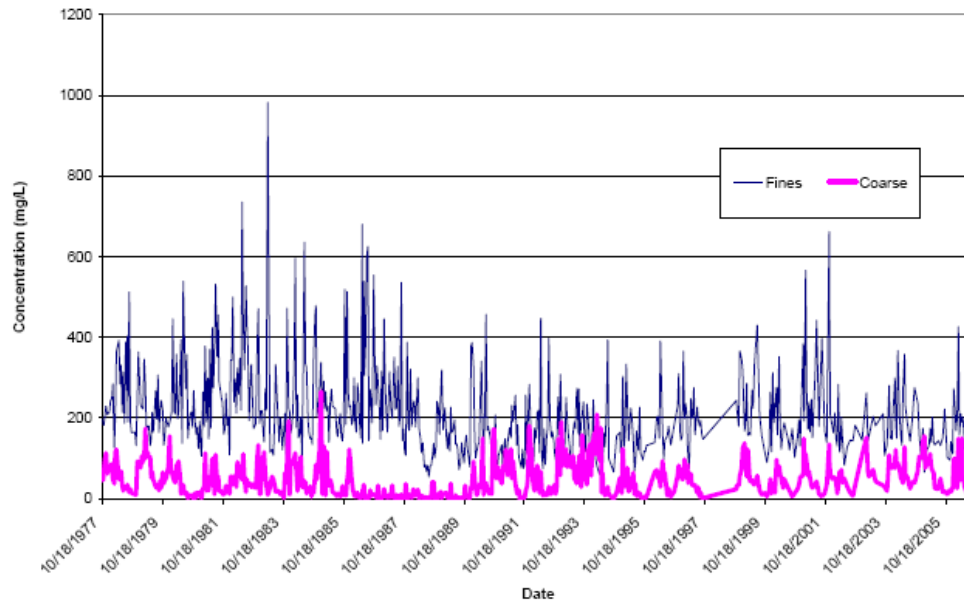
coincides with periods of peak sediment delivery during February through March (Roberts 1997, Allison *et al.* 2000, Bentley 2003).

Andrus (2007) compiled data pertaining to the grain size, volume of depositions, Mississippi River sediment load, and other information. The average median bed-material samples collected were: 0.0088 mm in Spring 2004, 0.0096 mm in Fall of 2004, 0.023 mm in Fall 2005 following hurricane Katrina, and 0.015 mm in Spring of 2006. All samples were predominantly in the silt range; however, a few sand samples were collected.

Andrus (2007) also compiled discharge and sediment concentration data for two gauging sites on the Mississippi River, at Tarbert Landing (RM 306.3) and at Belle Chase (RM 76.0). The average annual Mississippi River discharge at Tarbert Landing is shown as Figure 2.4 and sediment concentration for the same period and location is shown in Figure 2.5.

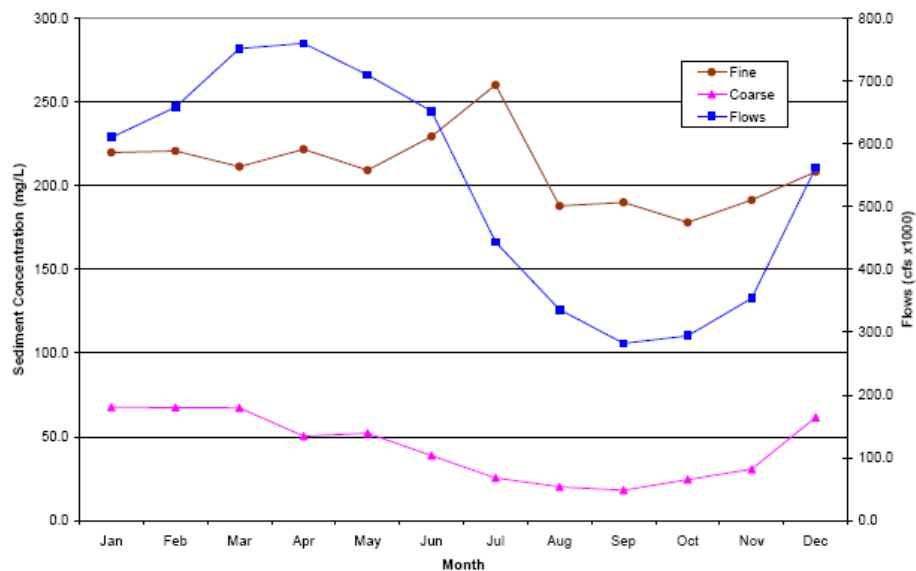


**Figure 2.4:** The average (1978 to 2006) annual Mississippi River discharge hydrograph at Tarbert Landing is shown (from Andrus (2007)).



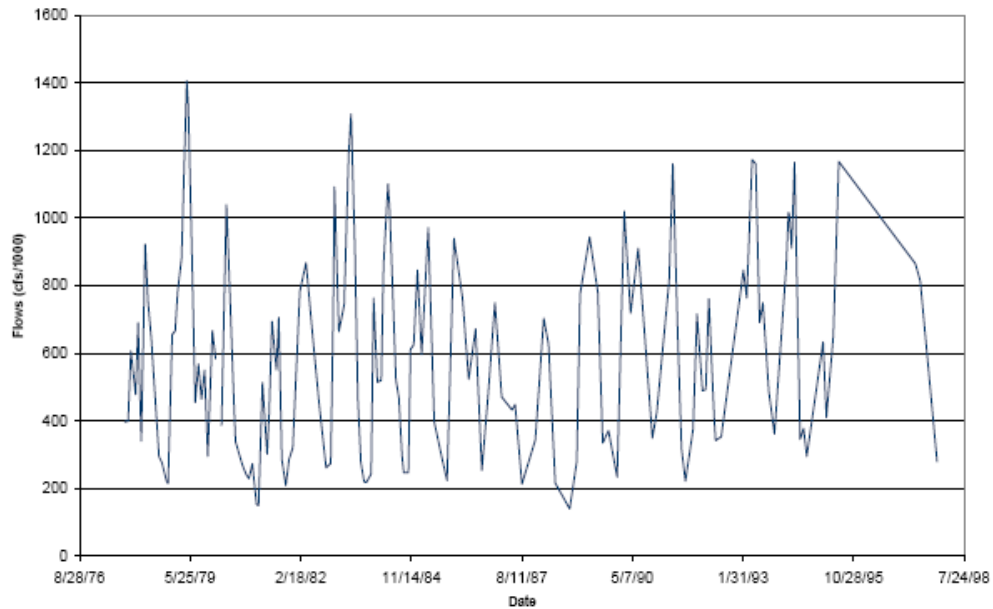
**Figure 2.5:** The average (1978 to 2006) annual Mississippi River sediment concentration hydrograph is shown for Tarbert Landing. Fine particles are smaller than 0.0625 mm.

Data from Figures 2.4 and 2.5 were combined by Andrus (2007) into composite annual hydrographs for sediment and discharge, which are shown in Figure 2.6.

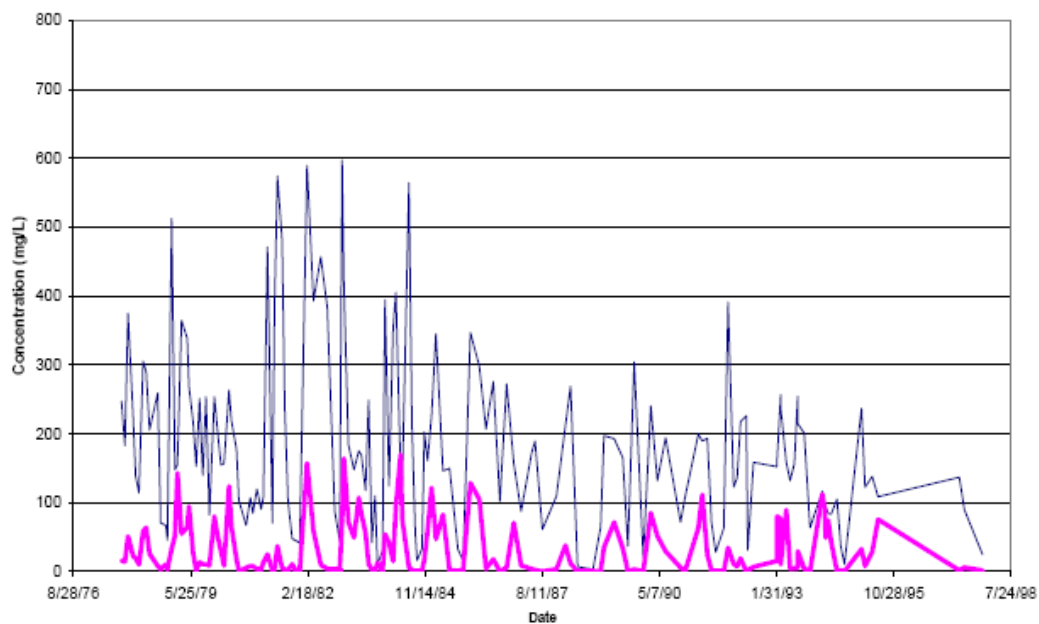


**Figure 2.6:** Composite annual hydrographs for sediment and discharge at Tarbert Landing are shown.

Figures 2.7 and 2.8 are Mississippi River discharge and sediment concentrations, respectively, for the Belle Chase gauge.



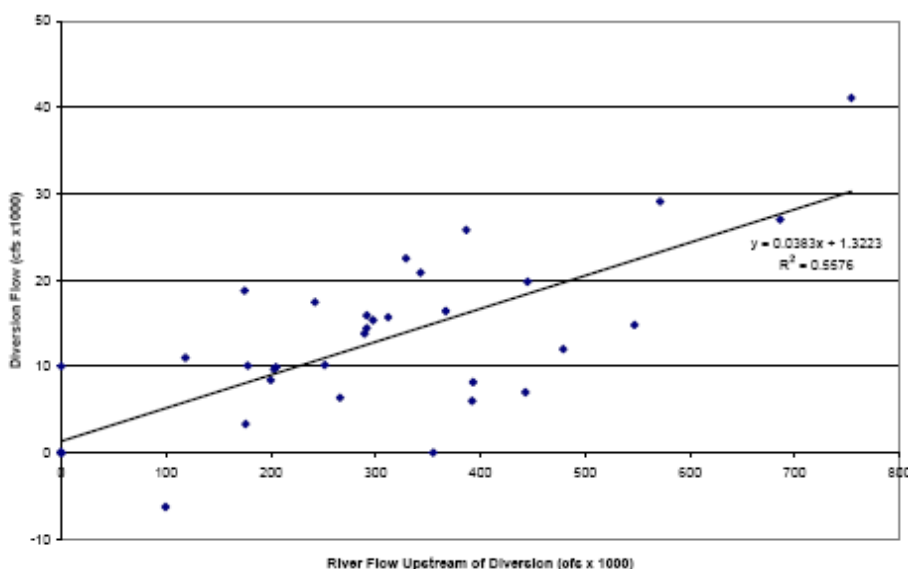
**Figure 2.7:** The discharge hydrograph for the Belle Chase gauge for the period 1978 to 1998 is shown.



**Figure 2.8:** Sediment concentration for the Belle Chase gauge is shown. The pink line represents coarse sediments (>0.0625 mm) and the blue line represents fine sediments (<0.0625 mm).

At Tarbert Landing, concentrations of fine sediment average approximately 225 mg/L from January to June, and peak in July slightly in excess of 250 mg/L. From August through November the concentration is less than 200 mg/L. Coarser sediment averages approximately 70 mg/L during peak flows and drop to approximately 35 mg/L for the lower discharges. The sediment concentration of fine material at Belle Chase averages approximately 180 mg/L and ranges from 5 mg/L to 600 mg/L, and coarse-material concentration averages 30 mg/L and ranges from 0 mg/L to 170 mg/L. Review of the available graphs suggests that the fine concentration is about the same and coarse-sediment concentrations are less at Belle Chase.

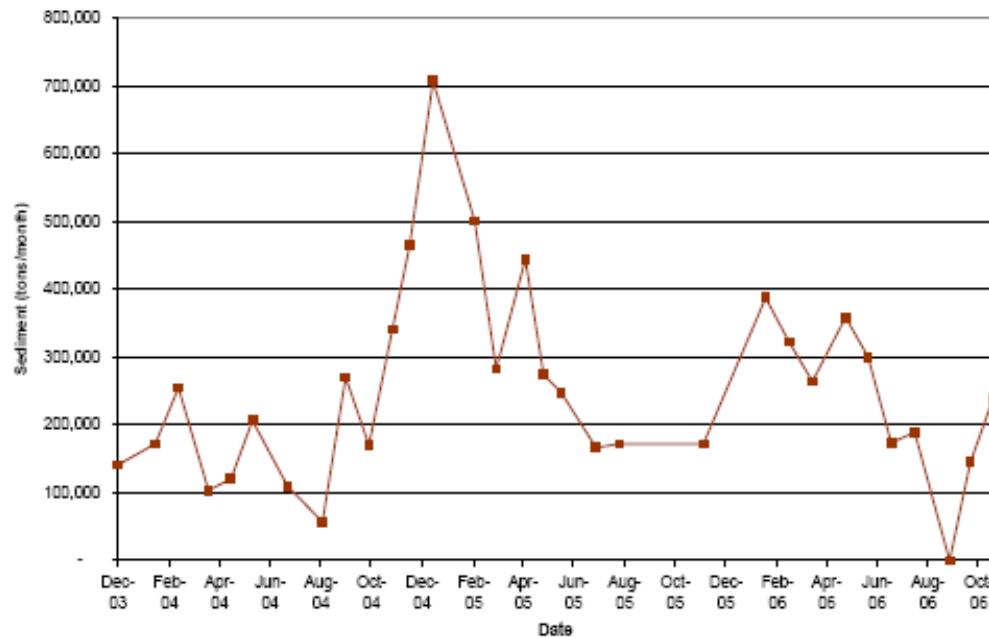
Figure 2.9 (Andrus 2007) portrays the relationship between measured Mississippi River discharge measurements and West Bay diversion discharge measurements. Andrus suggests that the points above the line are related to increased conveyance as the diversion becomes more efficient. The point of negative flow (from the West Bay into the river) occurred near a minimum discharge of 100,000 cfs on the Mississippi River. Andrus (2007) reported that the channel formed by the diversion into the bay was deepening, based on repeat surveys.



**Figure 2.9: Measured Mississippi River and West Bay diversion discharges.**

Average salinity was 0.45 parts per thousand (ppt). The estimated monthly sediment discharge into the Diversion is shown in Figure 2.10 (Andrus 2007). During the period of repeat surveys, Hurricane Katrina occurred and probably caused significant re-suspension of deposited sediment within the Bay; therefore, the net deposition for the period was negative. Andrus

(2007) estimated the potential sediment rates (Table 2.4) based on the sediment concentration, the diverted discharge into the Diversion, and on a range of percentage retention. The period of maximum sediment diversion can be estimated to be from January through May; however, as show in Figure 2.10, sediment concentrations may begin to increase in November. Andrus (2007) concludes that engineering strategies should place as much focus on receiving area configuration and trapping efficiency as sediment delivery to maximize sediment retention.



**Figure 2.10: Estimated sediment discharge passing through the Diversion (Andrus 2007).**

**Table 2.4: Estimated (a) sedimentation concentrations, (b) sediment flux, and (c) rates of sediment deposition (after Andrus (2007)).**

(a) Sediment concentrations (mg/L)

Location	Maximum	Minimum	Average
Tarbert Landing	992	57	259
Bell Chase	746	3	213
West Bay*	155	53	82

\*Values estimated from calibrated turbidity data.

(b) Sediment flux

Range	Date of Occurrence	Diversion Flow (cfs)	Diversion Flow (m <sup>3</sup> /s)	Monthly Sediment Flux (tons/mo)	Daily Sediment Flux (tons/day)
Maximum	February 2005	41,100	1,160	1.33 x 10 <sup>0</sup>	44,300
Average	January 2004 - November 2006	13,800	390	0.24 x 10 <sup>0</sup>	8,050
Minimum	September 2004*	3,310	94	0.04 x 10 <sup>0</sup>	1,250

\*Date of lowest observed positive flow (river to bay). A negative flow (bay to river) was observed in September 2006.

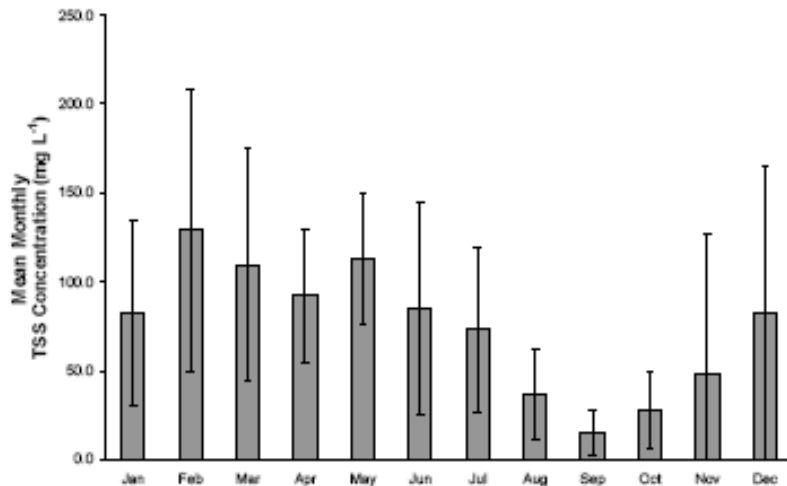
(c) Rates of sediment deposition

% Retention	Inches per Year		Centimeters per Year		Centimeters per Month if Deposited over 6 Months	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
25%	0.5	1.0	1.3	2.4	0.22	0.40
50%	1.1	1.9	2.7	4.8	0.45	0.81
75%	1.6	2.9	4.0	7	0.67	1.21
100%	2.1	3.8	5.4	10	0.90	1.61

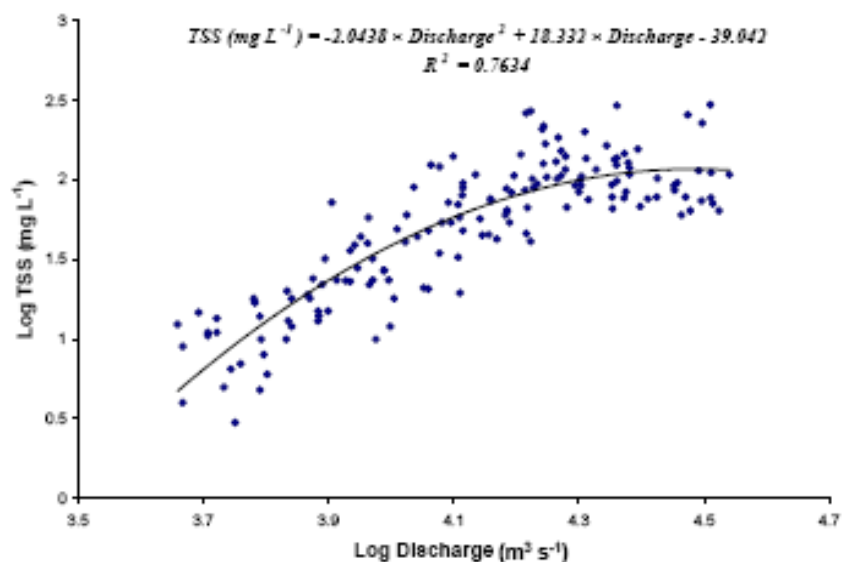
### 2.3.2 Caernarvon Freshwater Diversion

Upstream from the West Bay Sediment Diversion is the Caernarvon Freshwater Diversion (left bank, RM 81.0). Mississippi River water is diverted into the Breton Sound estuary through gated, box culverts, and as opposed to the free discharge at West Bay, the Caernarvon Freshwater Diversion is a controlled outlet. Snedden (2007) states that flow through the open gates can occur as the stage at Carrollton exceeds about 1.2 m North American Vertical Datum (NAVD) 88, and is designed to discharge up to 225 m<sup>3</sup> s<sup>-1</sup> of Mississippi River water. He reports (Figure 2.11) that the average monthly suspended sediment (TSS) concentration of the surface river water varies from 15 mg/L in September to 130 mg/L in February. The sediment-

rating curve is shown in Figure 2.12. Grain-size data collected by Snedden (2007) in 2003 showed a particle size distribution of 63% silt, 36% clay, and 1% sand.



**Figure 2.11:** Mean monthly TSS concentrations of Mississippi River surface water at Belle Chase, from 1991 to 2004. Error bars extend a standard deviation of the monthly mean value (Snedden 2007).



**Figure 2.12:** The relationship between TSS at Belle Chase and discharge for 158 measurements is shown (Snedden 2007).

During 2002 and 2003, Caernarvon was operated in a series of four pulses to determine the response of the estuary to large discharges of Mississippi River water. Table 2.5 provides summary data for the four pulsed diversion events. Snedden (2007) provided the data.

**Table 2.5: Summary data for four pulsed Caernarvon Freshwater Diversion events.**

Event	Date	Average Diversion Discharge (m <sup>3</sup> /s <sup>-1</sup> )	Duration (day)	Average River Discharge (m <sup>3</sup> /s <sup>-1</sup> )	Average TSS (mg/L <sup>-1</sup> )	Total Sediment Delivery (metric tons)	Metric tons day <sup>-1</sup>
Pulse 1	28 Jan – 11 Feb 2002	180	14	2.04 x 10 <sup>4</sup>	143	3.02 x 10 <sup>4</sup>	2.16 x 10 <sup>3</sup>
Pulse 2	04 Mar – 17 Mar 2002	166	14	1.22 x 10 <sup>4</sup>	57	1.13 x 10 <sup>4</sup>	0.81 x 10 <sup>3</sup>
Pulse 3	18 Feb – 03 Mar 2003	195	13	1.97 x 10 <sup>4</sup>	197	4.38 x 10 <sup>4</sup>	3.29 x 10 <sup>3</sup>
Pulse 4	17 Mar – 31 Mar 2003	193	15	2.01 x 10 <sup>4</sup>	101	2.46 x 10 <sup>4</sup>	1.64 x 10 <sup>3</sup>
Mean		184	14	1.81 x 10 <sup>4</sup>	125	2.75 x 10 <sup>4</sup>	1.98 x 10 <sup>3</sup>

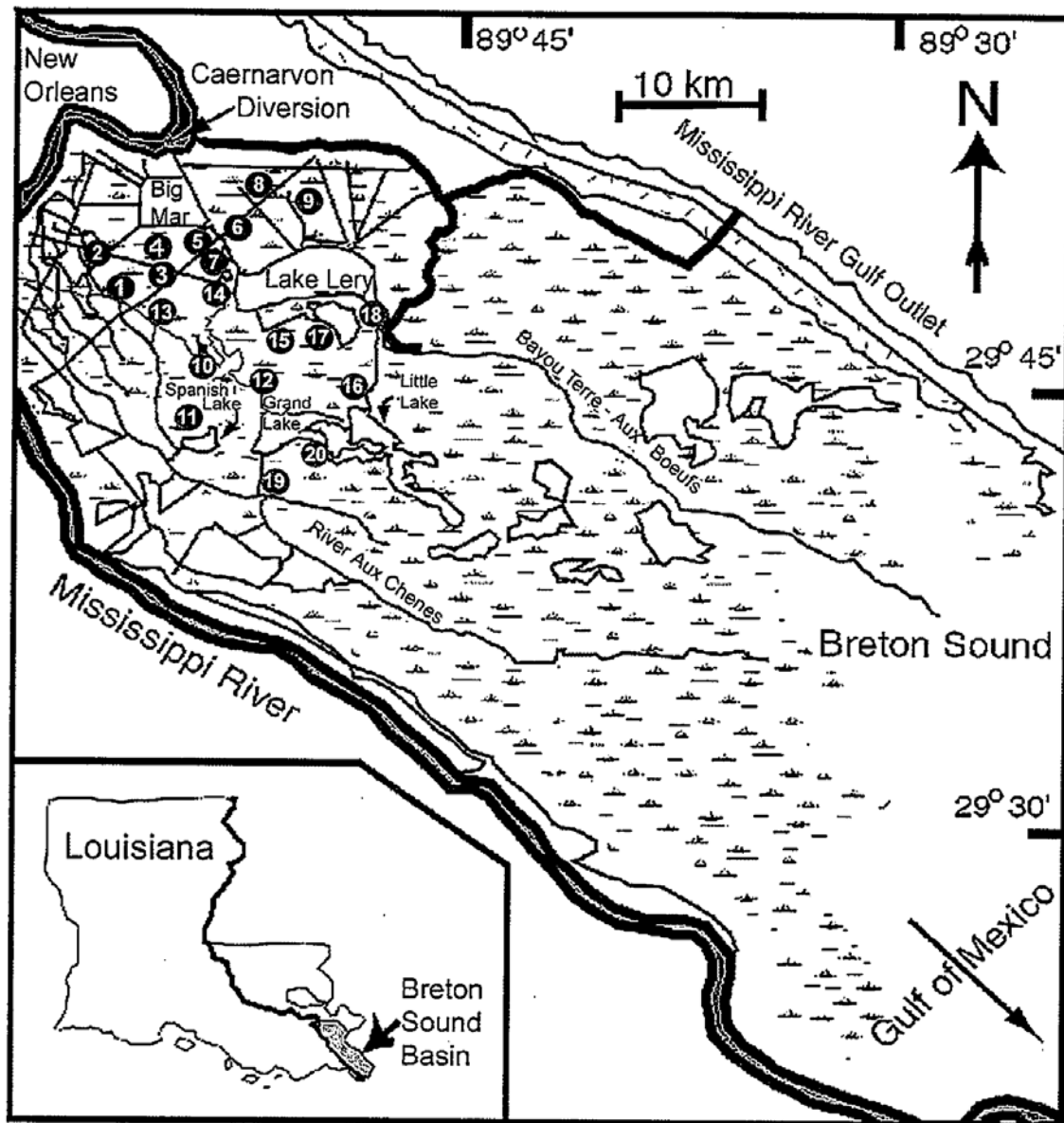
In Table 2.6, Snedden (2007) compares the sediment deposition measured as a result of the 1927 Caernarvon Crevasse, the observed deposition following the four pulses, and the maximum deposition if the Caernarvon diversion were operated to maximize sediment. He states that even if all the sediment from the four pulses were confined to the upper estuary, the loading rates would be insufficient to offset RSLR, estimated to be 2.8 to 3.8 mm/yr (sea-level rise of 1 to 2 mm/yr (Intergovernmental Panel on Climate Change (IPCC) 2001); subsidence of 1.8 mm/yr (CWPPRA 2002)). Operating the diversion structure to maximize sediment diversion would exceed RSLR.

**Table 2.6: Sediment delivery and deposition for Caernarvon (Snedden 2007).**

Event	Date	Area (km <sup>2</sup> )	Sediment Yield (x 10 <sup>6</sup> m <sup>3</sup> )	Deposition (mm)
Caernarvon Crevasse	1927	226	20	89
Caernarvon Observed	2002-2003	57	0.07	1.3
Caernarvon Maximum		57	0.32	5.6

DeLaune *et al.* (2003) reported that Louisiana coastal marshes represent a thin veneer of primarily organic soil material supporting vegetative growth overlying previously deposited mineral sediment.

Figure 2.13 is taken from DeLaune *et al.* (2003), and shows the location of twenty marsh sites downstream of the Caernarvon Freshwater Diversion.

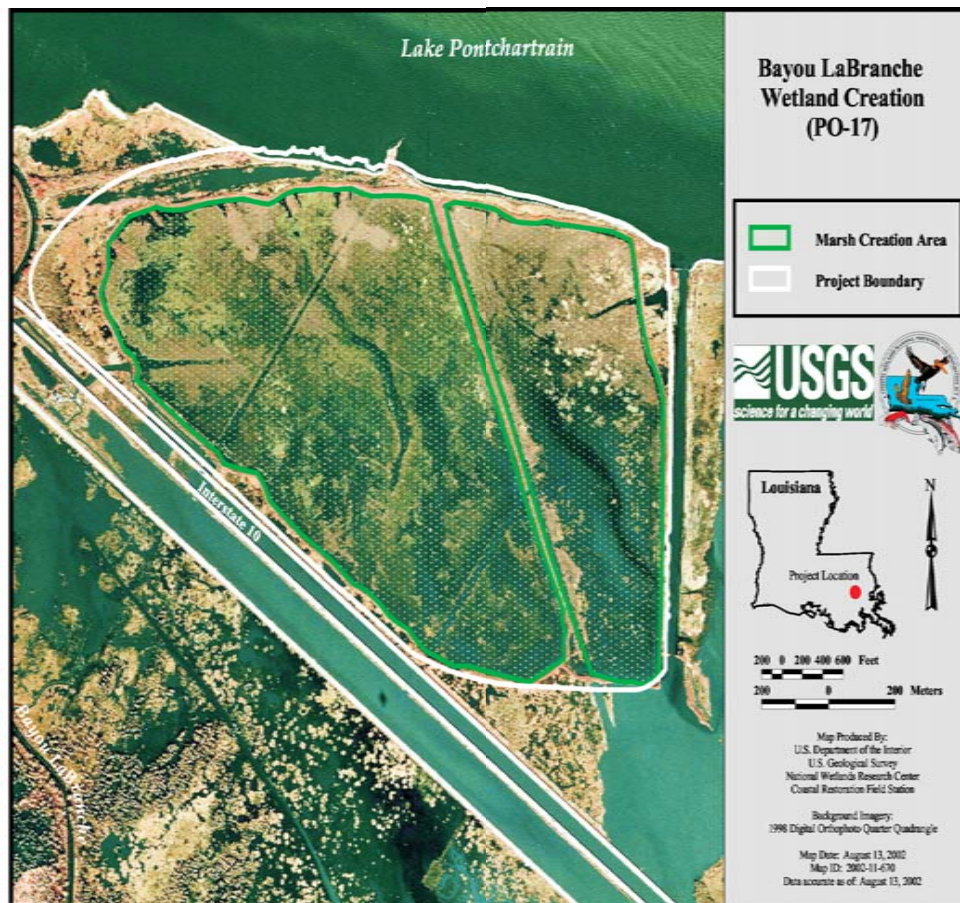


**Figure 2.13:** The Caernarvon Diversion and Breton Sound estuary are shown, along with twenty sample sites utilized by DeLaune *et al.* (2003). Notice the first ten sites are nearer the point of freshwater diversion.

Their results show that vertical accretion rates average 1.72 cm/yr for the nearer sites (Sites 1 to 10) compared with 1.34 cm/yr for Sites 11 to 20. Bulk density is greater for the nearer sites, with greater mineral and organic content in Sites 1 to 10. The paper provides significant quantitative data to document the results.

### 2.3.3 Bayou LaBranche Wetland Creation

The Bayou LaBranche project is on Lake Pontchartrain, located approximately 3 mi north of Norco, Louisiana (St. Charles Parish), and is bounded on the south by U.S. Interstate 10 and on the north by Lake Pontchartrain. Figure 2.14 is based on an aerial photograph and shows the project area.



**Figure 2.14:** The Bayou LaBranche project is shown in the aerial photograph (from Louisiana Coastal Wetlands Conservation and Restoration Task Force (2002)).

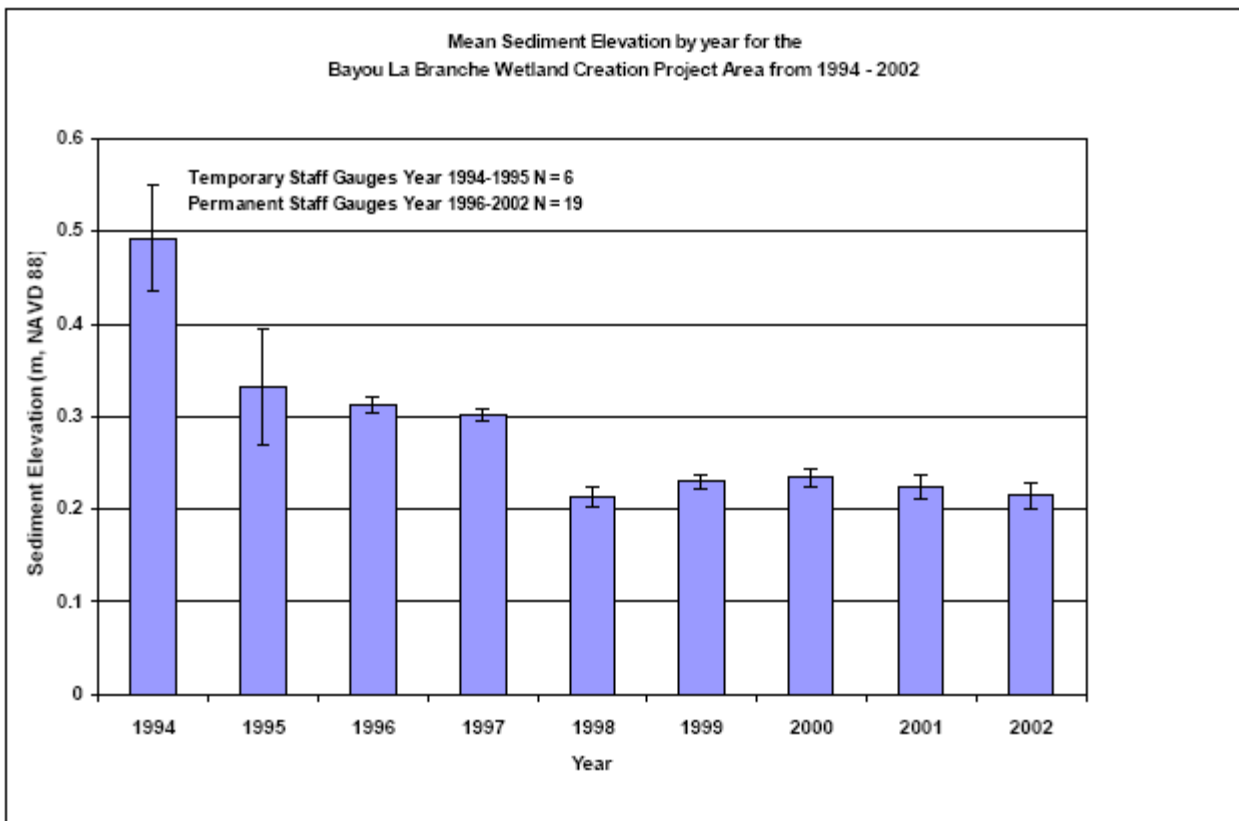
The primary cause of wetland loss in the area was the failure of agricultural impoundments and subsequent intrusion of salt water into the area. The general restoration strategy was to create an area of 70% land and 30% water within a period of 5 years following construction. A new emergent marsh was created in a 435-acre (174-ha) location that previously was open water by depositing 2.7 million cu yds of dredged sediment from Lake Pontchartrain. An earthen containment berm was constructed to protect the emergent marsh and to contain the deposited material. The construction was completed in 1994 (*Bayou LaBranche Fact Sheet*; Louisiana Coastal Wetlands Conservation and Restoration Task Force 2002; [www.LaCoast.gov](http://www.LaCoast.gov)).

Boshart (2003) documented the evolution of the deposited material for the period 1994 to 2002. Results at the constructed site were compared with an adjacent wetland, as shown in Figure 2.15.

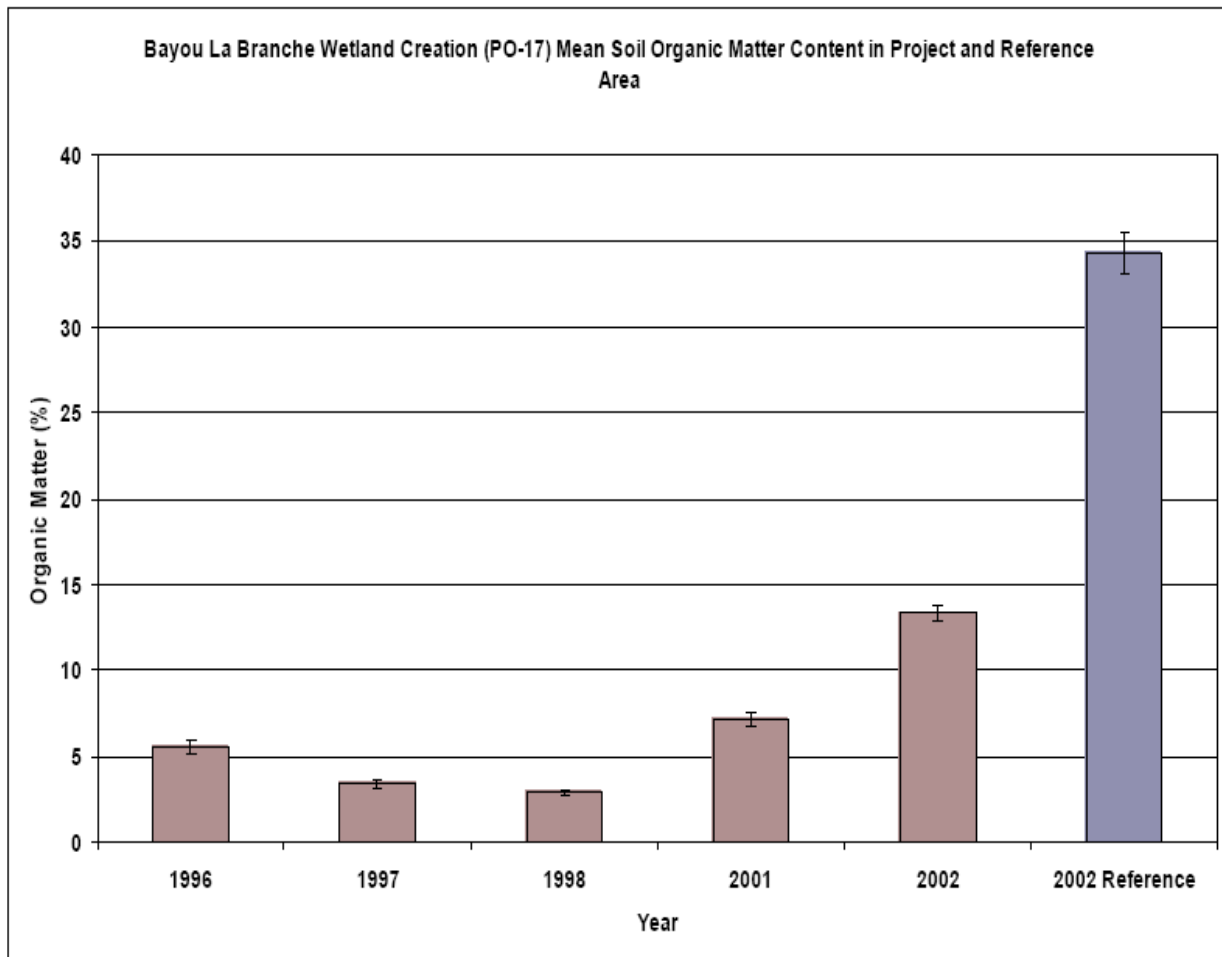


**Figure 2.15:** The proposed construction is shown on the left and the existing wetland (reference area) is shown on the right in this figure.

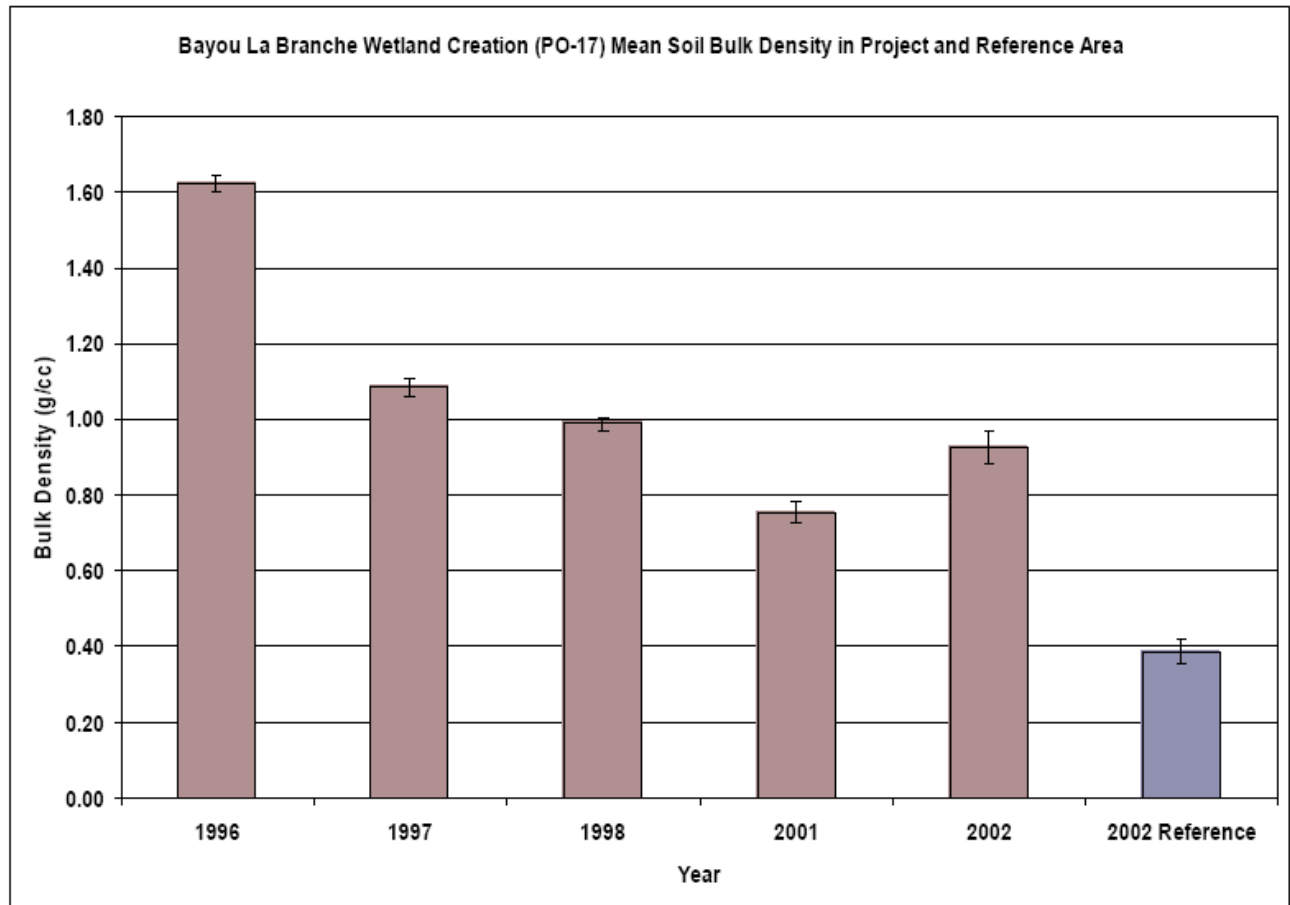
The following figures provide information pertaining to the change in sediment elevation, percentage organic matter, bulk density, and percentage of moisture. The average salinity for the project area (5.3 ppt) was greater than the reference-area salinity (4.6 ppt). Boshart (2003) attributed the difference in salinity to the impoundment of the project area that caused less flushing and increased concentration of salt due to evaporations. Sediment elevation decreased (Figure 2.16) as organic matter increased (Figure 2.17), and as bulk density decreased (Figure 2.18).



**Figure 2.16: The mean sediment elevation in the project area exhibits a decreasing trend during the period of measurement.**



**Figure 2.17: The percentage of organic matter increased through time and was significantly less than the percentage organic matter in the reference area.**



**Figure 2.18: The trend in the project area is to decrease bulk density, and move toward the reference-area condition.**

## CHAPTER 3

### ESTIMATES OF SEDIMENT RESOURCES REQUIRED FOR MARSH RESTORATION IN COASTAL LOUISIANA

The purpose of this effort is to present a reasonable likely range of sediment quantities required for marsh creation in coastal Louisiana using either: 1) mechanical placement of dredged material, or 2) freshwater diversions. In the latter case, benefits from nutrients are included in the assessment.

#### 3.1 Mechanical Placement of Dredged Material

The amount of sediment contained within a 1-km<sup>2</sup> marsh is a function of the marsh height and the sediment bulk density. Marsh height varies directly with depth, of course, but the top elevation of marshes also varies. For the computations herein, it is assumed that the marsh elevation is 1 ft mean sea level.

Bulk density is also highly variable, but is known to be a function of depth and salinity. Data summarized by Boustany (2007) suggest that estimates for upper-horizon (top 50 cm) bulk densities ( $\rho_i$ ) for fresh/intermediate marshes are about 0.1 g/cm<sup>3</sup>, and about 0.2 g/cm<sup>3</sup> for brackish/saline marshes. Below this horizon, a linear increase in bulk density at a rate of 0.6 g/cm<sup>3</sup>/m was assumed; yielding the following depth-averaged bulk densities (a fresh or intermediate marsh was assumed). Representative values of bulk density for fresh and brackish marshes are shown in Table 3.1.

**Table 3.1: Representative values of bulk density, weight, and volume for fresh and brackish mature marsh are shown.**

Depth (ft)	Bulk density (g/cm <sup>3</sup> )		Weight (T/km <sup>2</sup> )		Volume (cu yds/acre)
	Fresh/ Intermediate	Brackish/ Saline	Fresh/ Intermediate	Brackish/ Saline	
0.5	0.1	0.2	50,400	100,800	1,415
3	0.16	0.26	215,000	349,400	3,772
6	0.39	0.49	917,300	1,152,500	6,602

For the indicated depths, allowing for 1 ft above mean sea level as a finish grade, and using the indicated bulk densities, the quantities of sediment found within a 1.0-km<sup>2</sup> marsh are shown in Table 3.1. The limited available data on sediment bulk densities suggest that this factor can vary by 25%, which provides some notion of the uncertainty to be attributed to the values in Table 3.1.

The right column in Table 3.1 shows the volume of sediment required, and for typical depths the volume ranges from 1,415 cu yds/acre to 6,602 yds/acre. Previous experience by the U.S. Army Corps of Engineers (USACE), New Orleans District, indicates that approximately 4,000 cu yds of dredge material per acre of newly created wetland is required (Barras *et al.* 2004). Using the data in Table 3.1, the District average agrees with placement in approximately 3 ft of depth. In comparison, the Bayou LaBranche site required 4,345 cu yds of dredge material to create emergent marsh.

The quantities in Table 3.1 reflect the quantity of sediment within a mature marsh. The actual amount of material required to construct the marsh may be considerably greater than this value. Additional material may be needed to account for poor retention during placement and for vertical marsh adjustment. Retention of sediments for open water placement is generally quite poor; on the order of 40 to 50% for placement in 3 ft of water. For this reason, marsh is typically constructed within a contained dike system. The marsh is initially constructed at the construction grade, which is higher than the design grade to allow for initial consolidation and dewatering of the hydraulic fill.

Constructed marshes are subject to three modes of vertical adjustment:

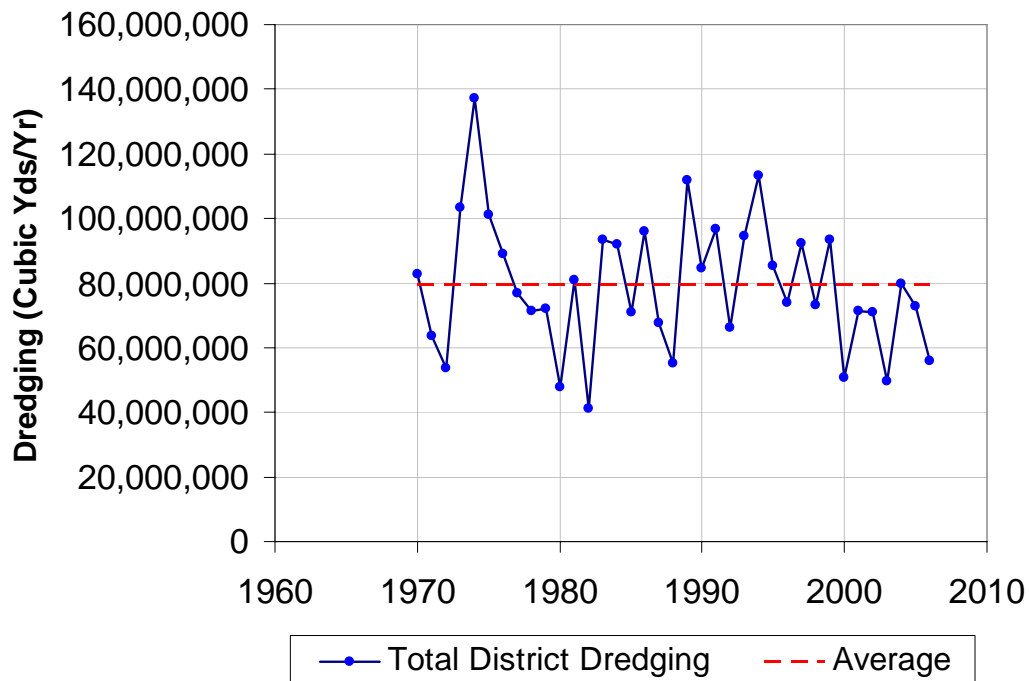
- 1) consolidation, as the hydraulic fill placed in the marsh dewateres (1 to 12 mo);
- 2) subgrade compression and settlement due to the overburden of placed material (estimated at 15% of consolidated overburden thickness; 1 to 5 yrs); and
- 3) RSLR, which consists of eustatic sea-level rise and regional land subsidence rates (century).

Factors 1) and 2) are accounted for with the bulk-density estimates. RSLR is not accounted for, however, and the effective life of constructed marshes can be quite low (10 to 20 yrs) where RSLR is high, suggesting the need for a continuing river water supply to flow through these sites to enhance organic accumulation.

Figures 2.16, 2.17, and 2.18 presented data from the Bayou LaBranche dredge deposition project. Through time (1994 to 2004), sediment elevation decreased, percentage organic material increased, and bulk density decreased. Deposition of the Bayou LaBranche material was made within a confining fill. Analysis of the fill material (e.g., settling column tests) can refine estimates consolidation during planning and design.

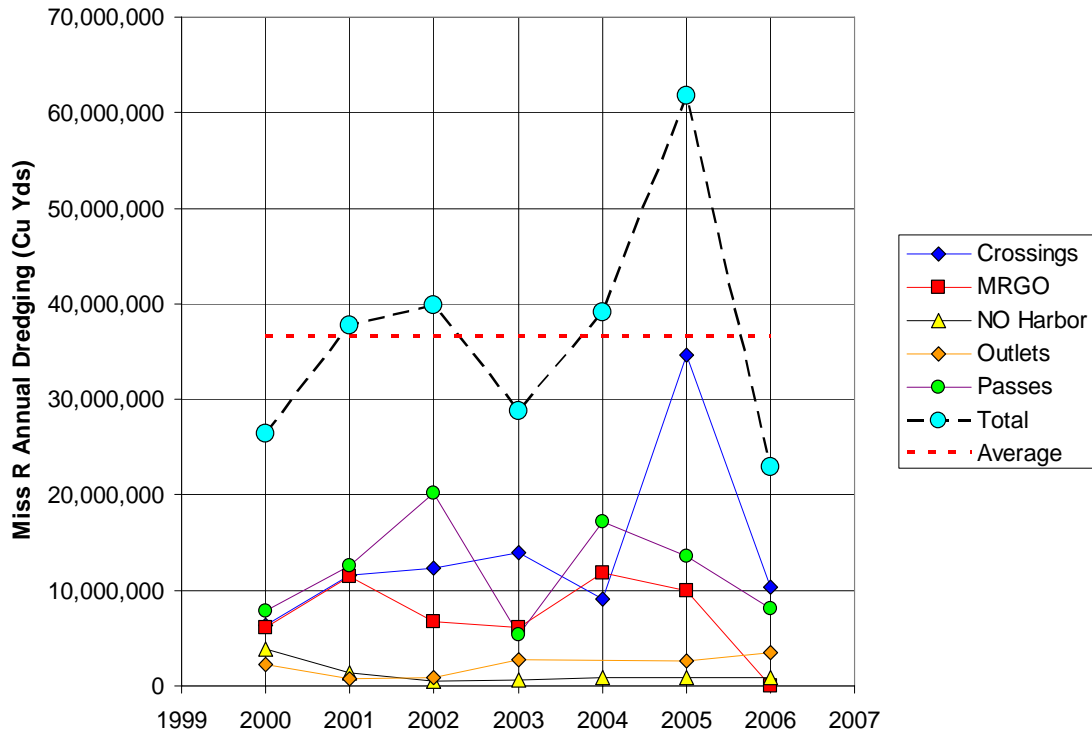
The New Orleans District, USACE, operation and maintenance dredging program dredges an annual average of 70 million cu yds (53.6 million m<sup>3</sup>). During 2004, approximately 14.5 million cu yds (11.1 million m<sup>3</sup>) was being utilized beneficially for the surrounding environment. At that time, the District proposed to use 30 million cu yds (23 million m<sup>3</sup>) of an average annual 70 million cu yds for beneficial use. Therefore, a total of 44.5 million cu yds (14.5 million cu yds existing plus the additional 30 million cu yds) was reasonably available for beneficial use, which is 64% of the annual average dredge volume. The District qualified this proposal by stating that a portion of the total volume was unavailable for beneficial use because some of the material is re-suspended from upstream maintenance (Barras *et al.* 2004).

It is important to review the dredging records to investigate any trends in the total dredging volume available and to get some idea of the location of the sediment stream. Figure 3.1 illustrates the variability of the total dredge volume of the New Orleans District. Dredging records were furnished by the District Operations Section, and each year the volume shown is the total of several sources, including the Mississippi River, Atchafalaya River, Calcasieu River, Mississippi River Gulf Outlet (MRGO), Gulf Intracoastal Waterway (GIWW), Old River Control, and numerous other projects. The average annual dredging for the period 1970 through 2006 is 79.3 million cu yds (61 million m<sup>3</sup>), which compares closely with the 70 million cu yds previously attributed to the District in the LCA (Barras *et al.* 2004). Variation in dredging quantities from year-to-year is dependent on the annual volume of river discharge, the shape of the hydrograph, project goals for the year, and other factors.



**Figure 3.1: The total volume of dredging occurring in each year for the New Orleans District is shown.**

Figure 3.2 shows primary sources of dredge material from the Mississippi River, the data having been extracted from the same source as Figure 3.1. The total average annual dredge volume from the sources shown in the legend of Figure 3.2 is 36.6 million cu yds (28.2 million m<sup>3</sup>). Comparison of the data in Figures 3.1 and 3.2 suggests that efficient use of the dredge-material resource would be affected by project availability to the dredge site.



**Figure 3.2: Annual average dredge volumes from several sources along the Mississippi River are shown.**

Using the percentage of annual average dredging reported by the District (64%) and the annual average from Figure 3.2 (79.3 million cu yds, 61 million m<sup>3</sup>), 50.7 million cu yds could be available for beneficial use. The District experience (Barras *et al.* 2004) suggests that on average, an acre of coastal land created requires 4,000 cu yds, which yields 12,667 acres (19.8 sq mi [51.3 km<sup>2</sup>]), assuming no loss of sediment in placement. Using the data in Table 3.1, at a depth of 0.5 ft the area created could be 35,830 acres, at a depth of 3 ft the area could be 13,341 acres, and at a depth of 6 ft the area could be 7,679 acres. As previously stated, the long-term sustainability of dredge-material placement is dependent on continued river water and sediment flow into the marsh for organic material to offset RSLR. The logistics and administrative challenges to arrange placement of the dredge-material resource at the disposal site would be significant. When new land is created with dredged materials, an additional 10% of material is needed to account for losses when placement is within a confined area. The amount of material needed is roughly double if an open water placement strategy is used, depending upon the water depth and tidal velocity.

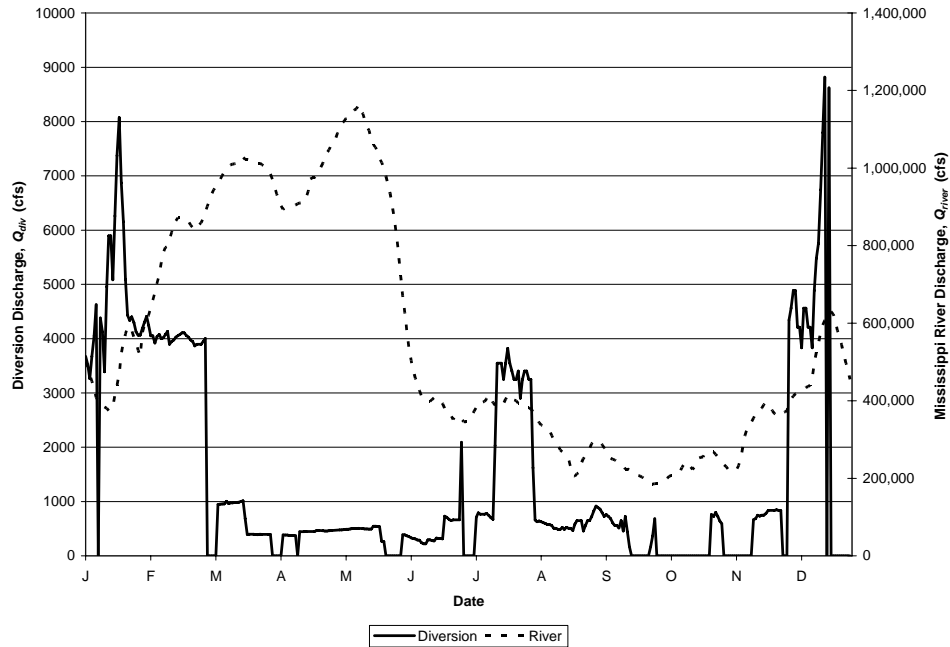
The amount of sediment needed to create marsh is a function principally of: 1) the marsh depth/height, 2) the bulk density of the sediments, and 3) the efficiency of the methods used to create the marsh. The amount of material in a marsh is a function of only the first two factors, depth and bulk density. The amount of material needed is roughly double if an open water placement strategy is used, depending upon the water depth and tidal velocity.

Marshes created with dredged material alone may succumb to RSLR in a short period (decades). In contrast, the continued supply of sediments and nutrients from diversions may sustain the marsh if flow volumes are sufficient.

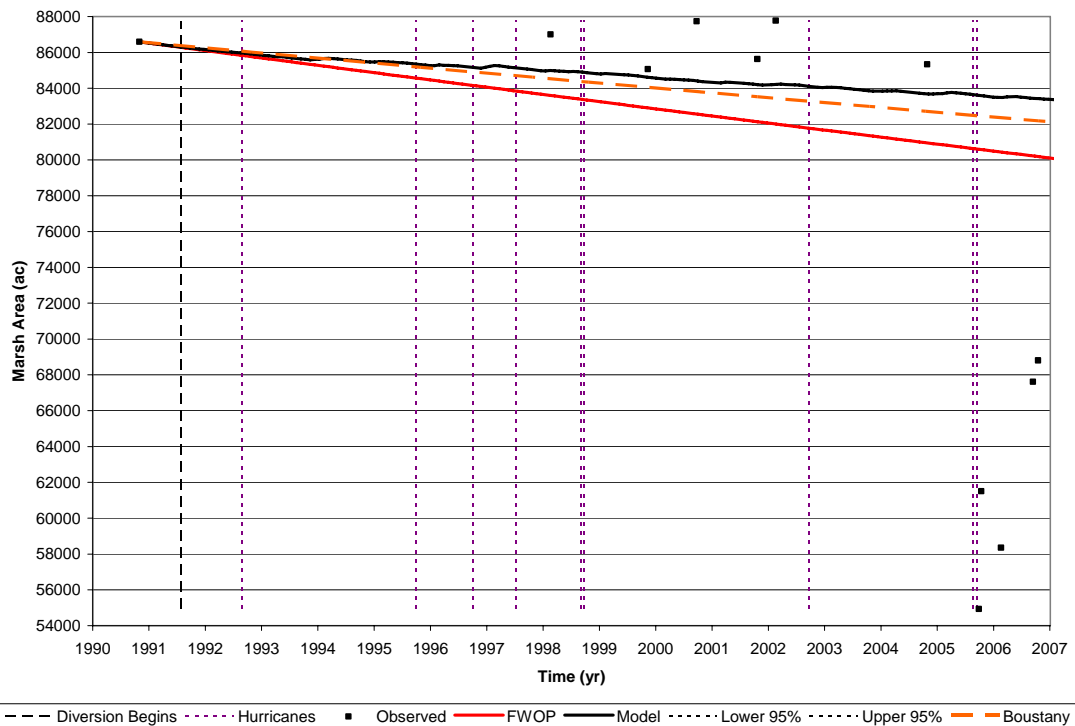
### **3.2 Freshwater Diversions**

Marsh can be created using freshwater diversions, wherein the sediments and nutrients of the diverted water contribute to both marsh creation and sustainability. To assess the potential for marsh creation using freshwater diversions, a desktop model developed for the Louisiana Coastal Protection and Restoration (LaCPR) Program (McKay *et al.* 2008) was used to simulate marsh creation at the Caernarvon Diversion. Their program was based on the Boustany (2007) composite nutrient and sediment model and to demonstrate the utility of their program, a simulation was made using the diversion and river hydrographs (Figure 3.3) of 1994, which was chosen as an approximate average year.

Figure 3.4 was taken from McKay *et al.* (2008) and shows observed values of marsh area, and estimates of marsh area using the Boustany (2007) model and the McKay *et al.* (2008) model. The estimated future without project (FWOP) is shown as the solid red line. Comparison of the Boustany (2007) model and the McKay *et al.* (2008) model indicated the value of the Caernarvon Diversion is reducing the rate of land loss. However, with all three trend lines sloping downward, it is clear that changes to the 1994 operation strategies are necessary to produce an increasing land area or a flat trend of no loss.



**Figure 3.3:** The diversion and Mississippi River hydrographs for 1994 are shown (from McKay *et al.* (2008)).



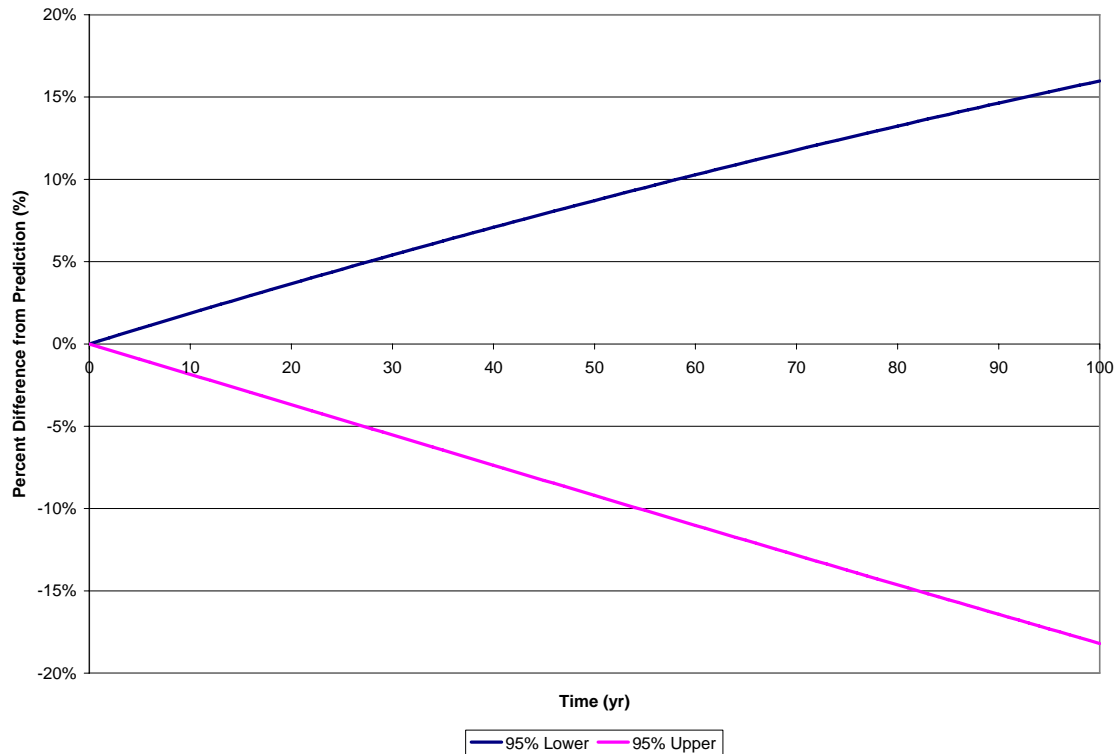
**Figure 3.4:** Trend lines of the FWOP, Boustany (2007) model and McKay *et al.* (2008) model; and observed data and hurricane occurrences (from McKay *et al.* (2008)). The upper and lower 95% trends are not shown.

Previous studies have shown that the operations of Caernarvon, while typical, are also highly inefficient in terms of marsh creation (Snedden 2007, McKay *et al.* 2008). Snedden (2007) showed that most of the flow of water and sediment from the river circumvents the marsh and flows down the marsh through two major routes at flows less than 3,500 cfs, and only when flows exceed 3,500 cfs does nutrients and sediment flow in sheet flow to the active marsh. Large pulses, as suggested by Day *et al.* (1995), not only provide discharges above the threshold, but also carry greater concentrations of sediment. McKay *et al.* (2008) have demonstrated that the same volume of water withdrawn at different times (to coincide with high river discharges) or from lower in the water column (with siphons, for example), would yield much higher sediment acreages in a given year. A Monte Carlo analysis of parametric uncertainty (Table 3.2) for marsh creation using freshwater diversions while maintaining a constant depth indicated that uncertainty grows over time as shown in Figure 3.5 (McKay *et al.* 2008).

**Table 3.2: The range of model variables used in the Monte Carlo simulation is shown (after McKay *et al.* (2008)).**

Values implemented	Max	Min	Mean	Std Dev	Best Guess	Range
Plant Productivity Rate, $P_r$ ( $\text{g}/\text{m}^2\text{y}^1$ )	4500	1500	3000	500	3000	$\pm 50\%$
% Retention	0.75	0.25	0.5	0.083333	0.5	$\pm 50\%$
Percent of N and P in Plant Biomass, $\%_{TNP}$	0.0102	0.0034	0.0068	0.001133	0.0068	$\pm 50\%$
Background Conc. of N and P, $TNP_{background}$ (mg/L)			0.35	0.08	0.35	$\pm 0.08$ , data
Source Conc. of N and P, $TNP_{source}$ (mg/L)			2	0.22	2	$\pm 0.22$ , data
Land Loss Rate	-0.0066	-0.0022	-0.0044	-0.00073	-0.0044	$\pm 50\%$
Average Water Depth, $H$ (ft)	3.3	2.7	3	0.1	3	$\pm 10\%$
Average Water Width, $B$ (ft)	69521	49521	59521	3333.333	59521	$\pm 10,000$ ft
Roughness Height, $z_o$ (m)	0.0015	0.0005	0.001	0.000167	0.001	$\pm 50\%$
Maximum Tidal Velocity, $U_{tide,max}$ (ft/s)	0.9	0.3	0.6	0.1	0.6	$\pm 50\%$
Coefficient	0.01635	0.00545	0.0109	0.001817	0.0109	$\pm 50\%$ , sed. data
Exponent	Do not vary				1.2297	Do not vary
Upper Horizon Bulk Density ( $\text{g cm}^{-3}$ )			0.1	0.044		data
Slope	0.8	0.4	0.6	0.066667		$\pm 0.2$
f fine sand	0.015	0.005	0.01	0.001667	0.01	$\pm 50\%$
f silt	0.945	0.315	0.63	0.105	0.63	$\pm 50\%$
f clay	1-fsand-fsilt					
f flocs	0.7	0.3	0.5	0.066667	0.5	$\pm 0.2$
Ws fine sand	0.0125	0.0075	0.01	0.000833	0.01	$\pm 25\%$
Ws silt	0.000375	0.000225	0.0003	0.000025	0.0003	$\pm 25\%$
Ws clay	8.75E-06	5.25E-06	0.000007	5.83E-07	0.000007	$\pm 25\%$
Ws flocs	0.00025	0.00015	0.0002	1.67E-05	0.0002	$\pm 25\%$

Assumed (Max - Mean)/3 = Std Dev



**Figure 3.5:** Results of the Monte Carlo simulation by McKay *et al.* (2008) indicate the extreme variation possible over extended time periods.

A desktop model assessment of the Caernarvon diversion was undertaken to assess the variability in marsh formation as a function of depth and tidal velocity, and to establish estimates of freshwater diversion quantities for marsh restoration. The model analysis (Table 3.3) showed depth to be the more significant factor. Using the 1994 operational hydrograph for Caernarvon and the river discharge hydrograph for that same year, roughly twice the time is needed to create 247.1 acres [1 km<sup>2</sup>] of wetland in 3 ft of water than is needed for this same acreage in 0.5 ft of water. The time to create this acreage of wetland in 6 ft of water relative to 0.5 ft of water is a factor of three to four.

**Table 3.3: The results from modeling of the Caernarvon Diversion using 1994 operational hydrograph are shown.**

Run No.	Variables		Annual Output			No. Days for 247.1 Acres
	Depth (ft)	Tidal Velocity (ft/s)	Nutrient (acres)	Sediment (acres)	Total (acres)	
1	0.5	0.1	24.7	135	159.7	565
2	0.5	0.6	24.7	134.8	159.5	565
3	3	0.1	24.7	65.8	90.5	997
4	3	0.6	24.7	48	72.7	1241
5	6	0.1	24.7	16.9	41.6	2168
6	6	0.6	24.7	12.1	36.9	2444

For the model simulations, 1994 diversion and river hydrographs were used as this year was very near average in terms of annual discharge volumes, and the peak magnitudes were well represented. Other model parameters are summarized in Table 3.4.

**Table 3.4: Model parameters employed for freshwater diversion simulations.**

Parameter	Best Estimate
Initial Land Area (acre)	0
Project Area (acre)	247.1 acre [1 km <sup>2</sup> ]
Average Water Depth, $H$ (ft)	0.5, 3, 6 ft
Average Water Width, $B$ (ft)	3,280 ft [1 km]
Maximum Tidal Velocity, $U_{tide\ max}$ (ft/s)	0.1, 0.6
Roughness Height, $z_o$ (ft)	0.005
Land Loss Rate (%/yr)	0.48
Bulk Density (g/cm <sup>3</sup> )	0.1 (upper 50 cm)
Plant Productivity Rate (g/m <sup>2</sup> /yr)	7,300
TNP Background (mg/L)	0.35
TNP Source (mg/L)	2.0
Nutrient Retention (%)	50
Percent of N and P in Plant Biomass (%TNP)	72

Model results show that for the designated area and hydrographs, 24.7 acres of wetland are created annually strictly from the nutrients in the diverted water. The remainder, which varies from 12 to 135 acres/yr, is due to the sediments. The sediment rating curve for Belle Chase was used to assess sediment delivery as a function of river discharge. Grain-size

distribution was 36% clay, 63% silt, 1% fine sand. It was further assumed that half of the clay fraction consisted of flocs. Sediment retention varied from 29 to 63%.

## CHAPTER 4

### CONCLUSION

Day *et al.* (2007) points out four general approaches to Louisiana coastal land restoration:

- 1) use dredged sediments to create and restore wetlands;
- 2) reconnect the river to the deltaic plain by river diversions;
- 3) restore barrier islands; and
- 4) restore hydrological processes that have been interrupted spoil banks, canals.

This report presents a preliminary assessment using approaches 1) and 2) using freshwater and sediment resources from dredging and riverine sources. Obviously, the array of possible scenarios for halting the rate of land loss for coastal Louisiana is varied; however, a single general approach has been selected and will be quantified.

The approach is to utilize dredged material to build a platform on which the vegetated marsh will be nourished by freshwater, sediment, and nutrients from a riverine source. Based on the work of Barras *et al.* (2004), a loss rate of 13.5 sq mi/yr [35 km<sup>2</sup>/yr] is used, along with an error range of  $\pm 25\%$ . The error range yields a maximum loss rate of 16.9 sq mi/yr [43.8 km<sup>2</sup>/yr], and a minimum loss rate of 10.1 sq mi/yr [28.2 km<sup>2</sup>/yr].

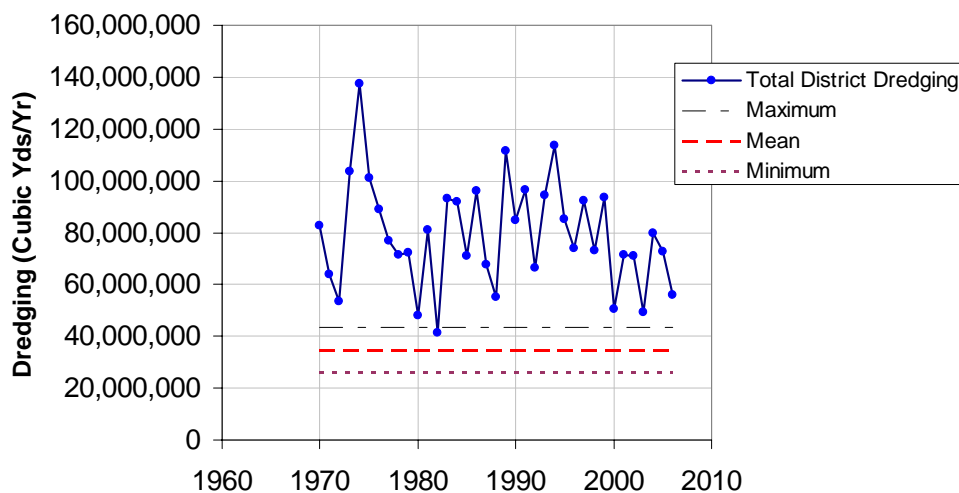
Table 4.1 lists the mean, maximum, and minimum land-loss rates in three different units, and includes the amount of dredge material required to compensate for each conditions. The dredge-material volumes are based on 4,000 cu yds/acre. These values would, of course, change depending on the depth of water at the site.

**Table 4.1: Land-loss rates and dredge-material quantities required to begin restoration are shown.**

	Land-loss Rate			Dredge Material (million cu yds)
	(sq mi/yr <sup>-1</sup> )	(km <sup>2</sup> /yr <sup>-1</sup> )	(acre/yr <sup>-1</sup> )	
<b>Maximum</b>	16.9	43.8	10,816	43.3
<b>Mean</b>	13.5	35	8,640	34.6
<b>Minimum</b>	10.1	28.2	6,464	25.9

As shown in Figure 4.1, the portion of the total annual dredging by the New Orleans District appears to be sufficient to satisfy the needs of beneficial use placement; however, several caveats must be carefully considered:

- The sources of dredge material may not coincide with convenient locations for beneficial placement, perhaps placing a burden of high cost on projects;
- Dredging records may be fraught with quality-control issues beyond the present standard of practice, for example the difficulty of obtaining an accurate hydrographic survey in the vicinity of hyper-concentrations of fine suspended material; and
- The range of acceptable sediment gradations for dredge-material placement is poorly defined, and a portion of the total dredged material may be unsatisfactory for the intended use.



**Figure 4.1: The total New Orleans District dredging is shown along with three levels of dredge material for beneficial use.**

Once the platform of dredge material is constructed, freshwater, nutrients, and sediment will be required to promote and sustain marsh development. Using the McKay *et al.* (2008) model, and assuming that marsh building of 0.5 ft/yr is sufficient, an average discharge of approximately 8,600 cfs of diversion would be required to build and sustain 13.5 sq mi of marsh. With a range of  $\pm 25\%$  of the mean flow, the maximum discharge would be 10,700 cfs and the minimum would be 6,414 cfs. By comparison, several existing diversions are listed in Table 4.2, with discharges of 8,000 to 600,000 cfs.

**Table 4.2: Listing of existing Mississippi River diversions below Natchez (from Andrus (2007)).**

<b>Diversion</b>	<b>River Mile (above head of passes)</b>	<b>Description of Control Structure</b>	<b>Purpose</b>	<b>Maximum Design Discharge (cfs)</b>	<b>Date Completed</b>
1. Old River Control Complex Low-sill	314.5	Controlled Spillway	Maintain Distribution of Flow and Sediment	500,000	1962
Overbank	314.5	Controlled Spillway	Flood Control	150,000	1962
Auxiliary	312	Controlled Spillway	Maintain Distribution of Flow and Sediment	350,000	1986
Hydropower	316.5	Controlled Spillway	Power Generation	170,000	1990
2. Morganza	285	Controlled Spillway	Flood Control	600,000	1963
3. Bonnet Carre	133	Controlled Spillway	Flood Control	250,000	1932
4. Caernarvon	85	Box Culverts	Freshwater Diversion	8,000	1991
5. Davis Pond	122	Box Culverts	Freshwater Diversion	10,050	2003
6. West Bay	4.5	Uncontrolled Channel	Sediment Diversion	20,000*	2003

\*Design discharge at 50% river stage. Initial discharge is planned to be increased to 50,000 cfs.  
(from CH2M Hill *et al.* (2004))

While making provisions for the sediment and river diversion quantities, planning the site to optimize marsh development with high percentages of sediment retention will be challenging. In addition, the scenario presented is in terms of average discharges and sediment concentrations; however, with large Mississippi River and Atchafalaya River discharges, such as occurred in 1973, the opportunity to divert more resources to marsh formation should be seized.

## CHAPTER 5

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